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RETIREMENT OF DR. A. C. BEST, C.B.E.

Dr. A. C. Best retired from the post of Director of Services in the Meteorological Office on 6 March 1966.

Alfred Charles Best was born in 1904 at Barry, Glamorgan. He was educated at Barry Grammar School and at University College, Cardiff, where he obtained his degree with first class honours in both mathematics and physics. He entered the Meteorological Office in 1926 and, after brief spells at Shoeburyness and Larkhill, was posted to Porton. This station has trained many distinguished meteorologists, and Best's contemporaries included both N. K. Johnson and O. G. Sutton who between them were to direct the Meteorological Office for thirty years. The meteorological studies at Porton were, and are, concerned principally with the dispersion of gases. Best's principal contribution was an experimental and theoretical study of the lapse rates of temperature and humidity in the lowest two metres of the atmosphere, an original and important work that has had a lasting influence on the development of diffusion theory.

In 1936 Best was posted to Malta and only returned to this country just before the outbreak of war. He spent the war years in Headquarters, apart from a brief spell towards the end when he was mobilized as a Wing Commander RAFVR and posted to India. In 1946 he joined the Research and Observatories Branch and so returned to the study of physical meteorology after a lapse of ten years. The subject had developed greatly in this interval. The importance of physical meteorology in aviation had come to be realized, and the Meteorological Research Flight had been established : while the explosive expansion of cloud physics that resulted from the first experiments in weather control was about to begin. The next eight or nine years were scientifically the most productive of Best's career, and in this period he wrote some fifty papers, covering almost the whole range of physical meteorology, though principally concerned with precipitation physics, radio-meteorology, and his original subject of diffusion. His best-known investigation was perhaps that concerned with the relationship between drop-size distribution and rate of rainfall, which is the basis of widely-used formulae for determinations by radar of rainfall intensity.

He was made Assistant Director for Special Investigations in 1953. The promotion did not interrupt his scientific work and in 1954 he was awarded

the degree of Doctor of Science by the University of Wales. From 1955 to 1960 he was Deputy Director, at first in charge of outstation services, and then, briefly, in charge of central services. In 1960 he became Director of Services, a post he held till his retirement. In the same year he was elevated to the rank of Commander of the Order of the British Empire, having been an Officer of the Order since 1953.

In this last, administrative phase, Dr. Best has guided the Services side of the Office through a series of major changes. To the layman, the most striking of these is probably the establishment of public weather centres in the great cities. More important in the life of the forecasting outstations, however, was the general introduction of facsimile, and the reorganization that facsimile rendered possible. Innovations such as the centralized forecasting systems for civil aviation are now so familiar that it is easy to forget how much hostility and suspicion they aroused when first proposed, and how cautiously they had to be introduced. Other, more recent innovations, introduced into the Services organization during Dr. Best's régime, will undoubtedly revolutionize the work of the Services side in the next few years although their effect is only beginning to be noticeable ; they include the use of the computed forecast charts, computed climatological summaries, weather radar, and satellite picture receivers.

Dr. Best's favourite hobby is photography and he has been for some years the President of the Meteorological Office Photographic Society.

To me, it has been a great privilege to be associated with Dr. Best in these last few years. He has been the most considerate of colleagues, and the facility and good humour that he always shows in argument have made the normal daily exchanges a constant pleasure. His many friends will wish him a long and happy retirement.

B. C. V. ODDIE

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CRITERIA CONCERNING FINE SPELLS IN SOUTH-WEST SCOTLAND DURING THE PERIOD MAY TO OCTOBER

By R. A. S. RATCLIFFE, M.A.

Summary.—From a study of 500-mb flow patterns over the years 1957–64, criteria are deduced for the forecasting of fine spells in south-west Scotland during the period May to October. The criteria are shown to be capable of forecasting about half of all fine spells occurring in south-west Scotland. The criteria were tested on independent data over the 5 years 1953–56 and 1965 with similar success.

Introduction.—Lowndes[1] and Ratcliffe[2] have deduced separate models for the forecasting of fine spells in south-east England but, at the time of writing, no corresponding work appears to have been carried out for the northern part of the British Isles.

To rectify this position the current investigation was undertaken. The stations chosen for the investigation were Renfrew and Prestwick and, for the purposes of this paper, a fine spell was defined as six consecutive 12-hour periods in each of which both Renfrew and Prestwick were dry or had not more than a trace of rain. The 12-hour periods corresponded to the periods reported in the *Daily Weather Report*, i.e. 0900–2100 GMT and 2100–0900 GMT.

Data used.—All the 500-mb charts for midnight in the 8-year period 1957–64 inclusive (May to October) were scrutinized with a view to uncovering any relationship which might exist between the 500 mb flow patterns and fine spells in south-west Scotland.

The dates of the fine spells were ascertained from the rainfall data in the *Daily Weather Reports* over the same period of years.

Preliminary results.—It soon became clear that fine spells in south-west Scotland were much more commonly associated with 500 mb highs in the vicinity of the British Isles than were those in south-east England. Table I illustrates this point : about 40 per cent of the fine spells at Prestwick and Renfrew which occurred in the 8-year period began with a 500 mb high near the British Isles and at least another 40 per cent were associated with a strong upper (500 mb) ridge which, in a substantial number of cases, developed into a high on the 500 mb surface later.

Another point soon emerged from a comparison of the dates of fine spells at Renfrew and Prestwick with those occurring at Kew and London (Heathrow) Airport over the same years : almost 80 per cent of the fine spells in south-west Scotland had a counterpart in south-east England although the Scottish ones were normally for a slightly different (and usually shorter) period (Table I shows this comparison).

TABLE I—ANALYSIS OF FINE SPELLS IN SOUTH-WEST SCOTLAND

Year	Total number of fine spells in south-west Scotland	Number with a counterpart in south-east England	Number with 500 mb High at onset	Number with strong ridges: Ridge persisted	Number with strong ridges: 500 mb high developed later	Others
1957	13	8	2	3	4	4
1958	9	3	5	1	1	2
1959	13	13	9	3	0	1
1960	8	7	4	2	2	0
1961	10	8	0	4	5	1
1962	11	7	8	2	1	0
1963	6	4	3	1	1	1
1964	7	5	2	4	0	1
Totals	77	55	33	20	14	10

These preliminary results suggest that some refinement of Ratcliffe's[2] criteria for south-east England, together with a more precise definition of the position of the 500 mb high and the flow pattern around it, might lead to successful results in forecasting fine spells in south-west Scotland. Following on these ideas the criteria in the next paragraph were deduced.

Forecasting criteria.—The results of the investigation suggest two independent criteria for forecasting fine spells. The first of these, based on the position of the strongest 500 mb flow coupled with an upper ridge, is as follows :

1. The strongest flow in the Atlantic area roughly from 40°N to 70°N, and 10°E to 50°W should be :

   (i) centred inside the area bounded by 55°N, 65°N, 40°W and a line joining 55°N 20°W to 65°N 10°W (see pecked lines on Figures 1–6), and

   (ii) from between 180° and 240°.

The strong flow may continue from approximately the same direction upstream or downstream outside the area the only requirement in (i), being that the core of the strongest flow should be centred inside the area in (i) at some place along its length but the core must not extend closer to Scotland than the defined area. The following provisos must also be satisfied :

(*a*) A strong 500 mb ridge with wind less than 30 knots across its axis, must be in an approximately north-south position between 20°W and 5°W. The 570-decametre contour line should reach at least 55°N.

(*b*) There must not be a 500 mb trough or vortex near the British Isles from approximately 48°N to 60°N and 5°E to 20°W.

(*c*) There must not be an equally strong 500 mb flow from between 270° and 310° immediately upstream from the strong flow.

2. The second set of criteria based on the position of the upper high at 500 mb and less restrictive 500 mb flow conditions is as follows :

(i) a closed-contour high on the 500 mb surface of 570 decametres or higher must be in the area 50°N to 65°N, 20°W to 10°E,

(ii) the 500 mb wind must be less than 40 kt within 400 nautical miles of the centre and over the British Isles (not beyond 10°E), and

(iii) there should not be a 500 mb trough or vortex over the British Isles from approximately 48°N to 60°N and 5°E to 20°W.

Normally the fine spell is about to begin or has already begun when either of the two sets of conditions above is satisfied.

Typical 500 mb charts illustrating the criteria are shown at Figures 1 to 3, and Table II gives a summary of results obtained.

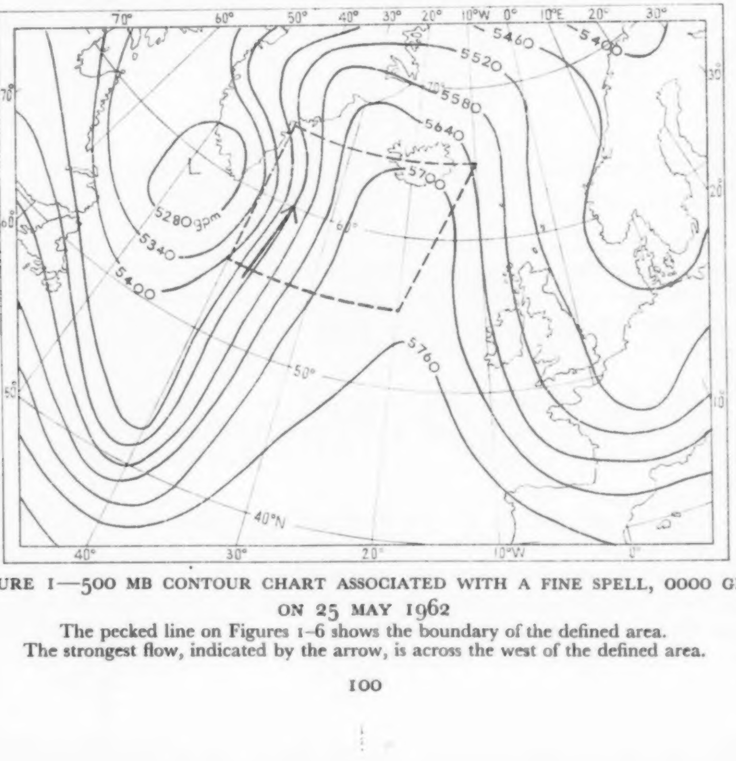

FIGURE 1—500 MB CONTOUR CHART ASSOCIATED WITH A FINE SPELL, 0000 GMT ON 25 MAY 1962

The pecked line on Figures 1–6 shows the boundary of the defined area.
The strongest flow, indicated by the arrow, is across the west of the defined area.

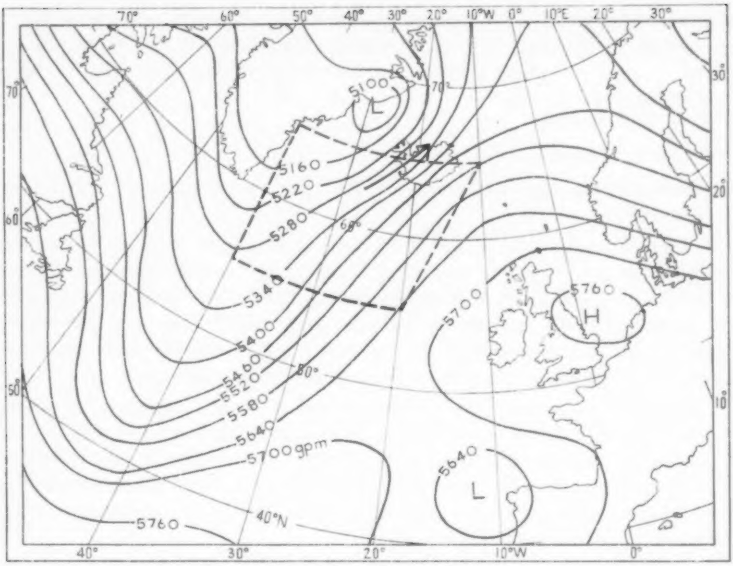

FIGURE 2—500 MB CONTOUR CHART ASSOCIATED WITH A FINE SPELL, 0000 GMT ON 19 OCTOBER 1965

The strongest flow, indicated by the arrow, is over the north-east of the defined area.

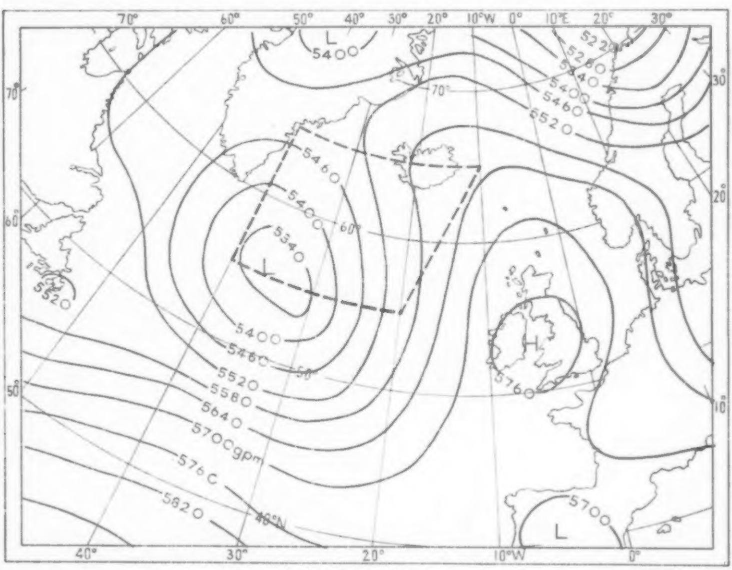

FIGURE 3—500 MB CONTOUR CHART ASSOCIATED WITH A FINE SPELL, 0000 GMT ON 4 JUNE 1962

TABLE II—NUMBER OF FINE SPELLS IN SOUTH-WEST SCOTLAND FROM MAY TO OCTOBER 1957–64 AND THE NUMBER FORECAST BY THE CRITERIA

Year	1957	1958	1959	1960	1961	1962	1963	1964	All years
Number of fine spells ...	13	9	13	8	10	11	6	7	77
Number forecast by the criteria	6	5	8	6	3	8	4	4	44*

*Twenty-one by criterion 1, 23 by criterion 2.

Comments on the criteria.—A few more comments on the criteria may be helpful.

(i) The critical value of 30 kt for the wind speed through the 500 mb ridge (proviso (*a*) on page 100) is very important as with stronger cross-axis flow there are many cases of fronts or small depressions breaking through the ridge to prevent the occurrence of any fine spell. The 500 mb wind at Stornoway and ocean weather station India (59°N, 19°W) may be used as marking the approximate northern limit of the 30-kt restriction.

(ii) As regards proviso (*b*) on page 100, it is not necessary to exclude upper vortices over France and Biscay as was the case for fine spells in south-east England. A 500 mb trough embedded in north-easterly winds over south-east England may be ignored but a trough in an approximately southerly flow in the western Channel or south of Ireland is a necessary restrictive condition (for example see Figure 4).

The 500 mb ridge to the west of the British Isles should not be too skew and in particular, with ridges near or east of 10°W at 50°N, the northern portion should not be so far east as to allow south-westerly upper winds over Scotland.

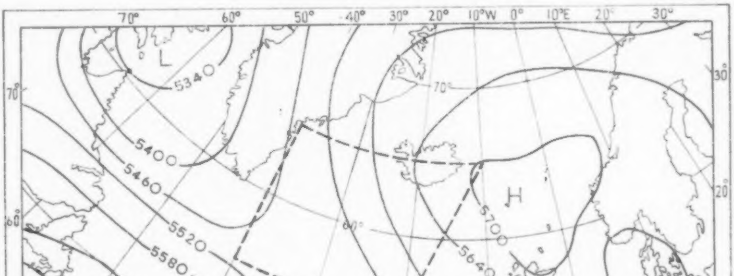

FIGURE 4—500 MB CONTOUR CHART NOT ASSOCIATED WITH A FINE SPELL, 0000 GMT ON 11 MAY 1960

Trough to the south of Ireland moved northwards.

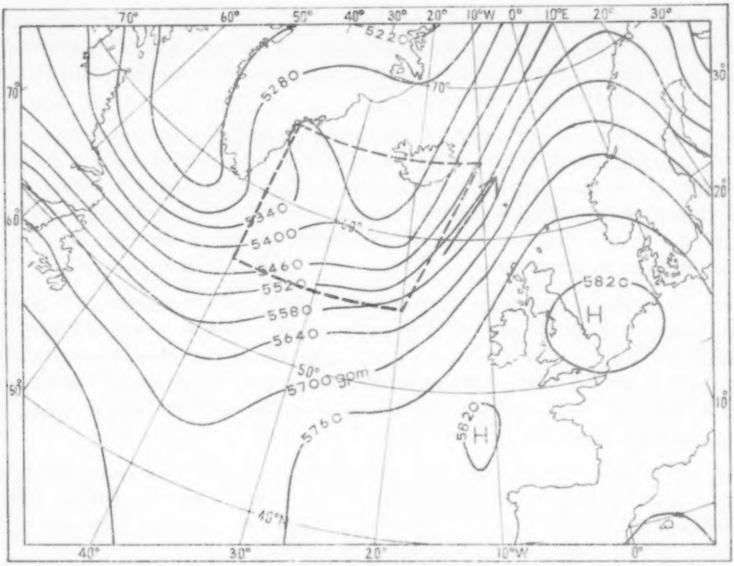

FIGURE 5—500 MB CONTOUR CHART NOT ASSOCIATED WITH A FINE SPELL, 0000 GMT ON 14 OCTOBER 1961

The south-westerly flow near north-west Scotland was too strong. The strongest flow, indicated by the arrow, is outside the defined area.

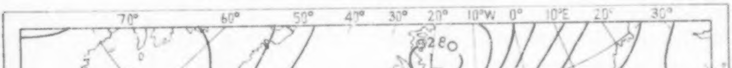

FIGURE 6—500 MB CONTOUR CHART NOT ASSOCIATED WITH A FINE SPELL, 0000 GMT ON 2 SEPTEMBER 1965

The strongest flow, indicated by the arrow, is across the centre of the defined area, but the North Sea trough moved westwards.

It is difficult to define precisely the term 'strong ridge' as thicknesses in ridges vary considerably over the months May to October but the most useful guide is to assume that the 570-decametre contour line on the 500 mb chart must extend northwards to about 55°N.

(iii) The exclusion of cases of strong north-westerly flow upstream from the south-westerly (proviso (*c*) on page 100) is a safeguard against a north-westerly jet causing some development of the upper trough between the two strong flows. This is really covered by the initial statement defining criterion 1 (page 100) but cases of equally strong north-westerly flow downstream are not so important.

(iv) In criterion 2 with an upper high centred south of about 56°N it is an additional safeguard if all the flow patterns of criterion 1 are satisfied, i.e. if the upper high is regarded as a strong ridge. Particular care is needed when the upper high is centred south of 56°N and east of the Greenwich meridian : in this case the 40-kt restriction on flow over the British Isles is important as far north as Stornoway (see Figure 5).

(v) Troughs in the 500 mb flow which are east of the Greenwich meridian become important only when the upper wind flow over the British Isles is predominantly from north or north-east. Figure 6 gives an example of an occasion of such flow when a fine spell did not follow.

Additional tests of the criteria.—It has been shown in Table II that the criteria can forecast more than half of the fine spells which occur in south-west Scotland. It is also necessary to show that the criteria do not occur on many occasions when there is not a fine spell. Therefore all cases when the criteria were satisfied in the years 1957–64 inclusive were examined and tested to see whether or not they were associated with fine spells. Results are shown in Table III.

TABLE III—ANALYSIS OF FORECASTS OF FINE SPELLS 1957–64

Year	Number of days on which criteria were satisfied with success*	with failure	Comments on failures
1957	24	3	6 May — Small amounts on 2nd and 3rd days 2 June — Last day of spell 31 Aug. — Followed by 2½ dry days
1958	14	4	On three occasions — Small amounts on 2nd and 3rd days 18 Oct. — Definite failure
1959	40	3	On three occasions — Small amounts on 2nd and 3rd days
1960	10	5	On three occasions — Small amounts on 2nd and 3rd days 5 Sept. and 4 June — Definite failures
1961	15	2	On both occasions — Small amounts on 3rd day
1962	23	9	On all occasions — Small amounts on one day
1963	14	3	On one occasion — Last day but one of a spell 15 Oct. and 15 June — Definite failures
1964	8	3	One failure on 3rd day 25 June and 23 July — Definite failures
Totals	148	32	7 total failures

*Criteria were applied to the 0000 GMT chart for all days and were deemed to be satisfied with success if followed by 3 days of dry weather starting at 0900 GMT.

Although the number of failures is higher than for the corresponding data for south-east England, most of the failures only involve small amounts of rain on one day and the proportion of total failures is only about 5 per cent.

As a further check the criteria were tested on completely independent data for 1953–56 and 1965 (5 years in all) with the results shown in Tables IV and V.

TABLE IV—ANALYSIS OF FORECASTS OF FINE SPELLS IN TEST PERIOD 1953–56 AND 1965

Year	Number of days on which criteria were satisfied with success*	with failure	Comments on failures
1953	23	1	4 Sept. — Rain at Prestwick only on one day
1954	9	1	25 Aug. — Small amounts of rain on 2nd and 3rd days
1955	29	3	11 Aug. — 0·3 mm at Prestwick on 12th only
			7 Aug. and 23 Oct. — Small amounts on 2nd and 3rd days
1956	12	4	2 Sept. and 11 Oct. — Small amounts on 3rd day
			21 July — Followed by 2½ dry days
			27 Oct. — Spell began on 29 Oct.
1965	18	3	On all occasions — Small amounts on 3rd day
Totals	91	12	1 total failure 27 Oct. 1956

*Criteria were applied to the 0000 GMT chart for all days and were deemed to be satisfied with success if followed by 3 days of dry weather starting at 0900 GMT.

TABLE V—RESULTS OF USING THE CRITERIA OVER TEST PERIOD 1953–56 AND 1965

Year	1953	1954	1955	1956	1965	All years
Number of fine spells observed	12	5	10	11	12	50
forecast	6	3	5	6	6	26*

*Thirteen by each of the criteria.

It is encouraging to note that the results on independent data are rather better than those which followed from the original data.

Conclusions.—It is shown that about half of the fine spells which occur in south-west Scotland can be forecast by considering the 500 mb flow pattern over the British Isles and in an area of the Atlantic bounded by 55°N and 65°N, 40°W and a line joining 55°N 20°W to 65°N 10°W.

If the flow in this area is south-westerly and is the strongest in the whole Atlantic area with a strong 500 mb ridge to the west of the British Isles, then, with certain restrictive conditions, a fine spell can be forecast with a fair amount of confidence for south-west Scotland during the months May to October.

A 500 mb high cell in the area bounded by 50°N to 65°N and 20°W to 10°E, coupled with less restrictive 500 mb flow patterns over the Atlantic and British Isles, also make it possible to forecast fine spells in south-west Scotland with reasonable confidence.

REFERENCES

1. LOWNDES, C. A. S.; Forecasting dry spells of three days or more in south-east England from May to October: a revised model. *Met. Mag., London*, **94**, 1965, p. 241.
2. RATCLIFFE, R. A. S.; New criteria concerning fine spells in south-east England during the period May to October. *Met. Mag., London*, **94**, 1965, p. 129.

551.501.81:551.576.1:551.576.4

EXAMPLES OF CLOUD DETECTION WITH 8·6-MILLIMETRE RADAR

By W. G. HARPER, M.Sc.

Introduction.—A previous paper[1] based on an 18-month study at the Royal Radar Establishment, Malvern, reached conclusions on the value for meteorological purposes of 8·6-millimetre wavelength radar. Studies are now presented of selected records illustrating the resolution given by the radar when used for cloud detection. While the selection of a single record of each cloud type has its dangers, and may not be representative, nevertheless the examples which follow will illustrate the unusual capabilities of the equipment.

Millimetric radar gives echoes from small cloud particles and therefore can be used for cloud detection. Because a narrow radar beam is possible the millimetric radar gives close resolution. The radar was operated pointing vertically. Signals were displayed on a cathode-ray tube as an intensity-modulated display linear in height. By photographing the display and applying a slow lateral displacement to the trace a height–time pattern was built up of the cloud and precipitation passing overhead. Electronic markers provided a height scale on the records in thousands of feet. The horizontal band of echo at the bottom of each radar record (e.g. Plate I) is caused by the out-going transmitter pulse, which prevents observation of the lowest 1000 feet. The occasional dark vertical lines on the height–time patterns should be disregarded ; they are the result of measurements of echo intensity. Sky-camera records are included when available. They are not strictly whole-sky photographs, for the angle of acceptance of the lens was only 140 degrees. The camera was usually tilted 20 degrees from the vertical to bring in the horizon in one sector, as an aid to cloud identification. In these sky-camera records the zenith has been marked with a cross. Observers' detailed reports of cloud and weather were also available, usually at 5-minute intervals. More complete details of the equipment and a photograph of its 16-foot diameter aerial can be found in the earlier paper.[1]

Examples of records taken with 8·6-millimetre radar.—

(i) *High cloud detection.*—Examples are shown in Plate I of echoes from cirrus and cirrostratus. Cirrocumulus is not covered because this cloud passed through the zenith on very few occasions and no useful records were obtained.

Plate I (*a*) shows the detection of well-developed cirrus cloud on 24 September 1962 in the layer between 22,000 and 24,000 feet. The cirrus was probably the precursor of a cold front which had become almost stationary across Ireland to southern Scotland and the Norwegian coast. At 0910 and 0915 GMT the sky was obscured with stratocumulus at about 2000 feet (see also page 110), but by 0925 this had broken, and the observer was able to record 6/8 cirrus fibratus. The cirrus at 0910 and 0915 GMT is unlikely to have been very different. The sky-camera record for 0925, which is reproduced, shows cirrus tufts visible through a gap in the stratocumulus layer. The uniformity of the fallstreaks in the radar pattern, individually only a few hundred feet across, suggests that ice crystals with a very uniform fall velocity

were growing to a detectable size at 24,000 feet (temperature −26°C), and evaporating to become undetectable at 22,000 feet. The 0°C level was at 12,000 feet. There is a suggestion of a 'generating cell' at 24,000 feet at 0910 GMT of the type described by Marshall,[2] but it is not well defined. Winds were south-south-west over Malvern at cirrus levels, probably about 30 knots, giving a horizontal spacing of cirrus fallstreaks of the order of one mile. This would have been difficult to determine visually because of overlapping of fallstreaks as viewed from the ground. The slope of the streaks on the height–time pattern is evidence that the wind increased with height in the layer above 22,000 feet.

Plate I(*b*) shows the detection of cirrus and cirrostratus just ahead of a cold front at 1600 GMT on 31 October 1961. The front was approaching from the west and passed through Malvern some time after 1800 GMT. It was near dusk when this record was obtained, and it was not possible to use the sky camera, but the observer reported that at 1600 there was 7/8 cirrus and cirrostratus, 6/8 altocumulus and altostratus base about 12,000 feet (apparently not detected by radar), and 3/8 stratocumulus with base at about 2000 feet (see also page 110). The strong echo between 21,000 and 24,000 feet shows closely spaced fallstreak effects, with rapid growth of ice crystals probably occurring at or just below 24,000 feet. In the original negative there is a well-defined but weak echo both above and below these levels, down to 19,000 feet in faint fallstreaks, and at 25,000 feet where the echoes had a distinctly hummocked appearance, rather like those recorded from shallow cumulus (see page 109 and Plate III(*a*)). This echo could not have been affected appreciably by attenuation,[1] and probably defines precisely a cumuliform top to the layer. The temperature at 25,000 feet was −30°C, and the 0°C level was at 9000 feet. The winds were westerly at cirrus levels, and were probably about 50 knots at 24,000 feet in the Malvern area. Thus the calculated horizontal spacing of fallstreaks was roughly 0·5 miles.

Plate I(*c*) shows that by 1650 GMT the cirrostratus echo had increased both in thickness and intensity with the approach of the cold front. The echo has a fibrous top, an effect of attenuation or of growth, still mainly at 24,000 feet, but a much firmer base. At 1650 GMT 7/8 stratocumulus prevented visual observation of higher clouds, but at 1635 when the stratocumulus layer was well broken the observer reported an 8/8 layer of altostratus and altocumulus at 10,000 feet. Features in the pattern are the appearance of a 'bright band' at the melting-level at 9000 feet at 1653 GMT, and the increase of echo intensity in the fallstreaks of rain below this, a greater increase than any which can be attributed to the decreasing range of detection. This and the weakness of the bright band are almost certainly due to shear of the shafts of precipitation across the height–time section recorded by the radar. They illustrate the difficulty in interpreting variations in echo intensity made with a vertically-pointing radar. The persistence of these fallstreaks without evaporation may be evidence that they were falling through medium cloud for much of their depth, as is suggested by the observation at 1635. The stratocumulus layer is marked by a weak band of echo centred at 3000 feet, and here the fallstreaks show a reversal of slope. The point can usefully be made that a reversal of slope in a fallstreak on a height–time display does

not imply a reversal of wind direction. A reversal of slope or a vertical section of trail on this display occurs in any layer in which the wind becomes equal to the wind at the generating level of the trail. The theory of this is given by Marshall.[2] Trail slope on a height–time display is extremely sensitive to particle fall-velocity.

(ii) *Medium cloud detection.*—Plate II(*a*) is a good example of detection of altocumulus. It was associated with a weak trough of low pressure moving southward over the North Sea, while an anticyclone was centred over Ireland. The echoes have a fairly uniform base at 6000 feet and top at 8000 feet. The Aughton upper air sounding at 1130 GMT showed that the 0°C level was at 5000 feet, and that the temperature was −6°C at 8000 feet, with a pronounced 2 degree C rise of temperature and quite dry air immediately above. The height of the inversion is in good agreement with the echo top. Since temperatures in the cloud were no lower than −6°C and there was no evidence of seeding by ice crystals from higher levels it is likely that the cloud particles were unfrozen and the cloud was a water cloud. The available records suggest that this narrow-beam millimetric radar can at times validly distinguish between water cloud and ice cloud. Ice cloud has a more fibrous appearance on the display. Water cloud is more blobby in appearance, as in this example, and the weaker portions of the echo are diffuse rather than fibrous. With a wider-beam millimetric radar much of this detail would be lost.

The wind at altocumulus level was 020 degrees 18 knots (Aughton 1730 GMT), so that the time scale on the height–time pattern corresponds to a horizontal distance scale which is exactly twice as large as the vertical height scale. Thus the active cells in the pattern are rather deeper than they are broad. In parts of the record at about this time faint fallstreaks can be seen extending down to 5000 feet. The trace of echo at 5000 feet at 1639½ GMT is one of these. It can be tracked back to a tuft of echo in the main layer at 1638½.* The sky-camera photographs of Plate II(*a*) show typical altocumulus.

Plate II(*b*), recorded on 1 November 1961, shows initially a much stronger echo from cloud which, at 1425 GMT, was giving very slight rain at the ground. The observer's description was of 'spots of rain in the wind'. A warm front was very close to Malvern at the time. The front moved through rapidly however and few stations in south-west England reported more than a trace of rain. At 1430 GMT, 7/8 altostratus and altocumulus was recorded, with 2/8 stratocumulus base 3000 feet. It is difficult to discern much detail in the cloud photograph at this time. The height–time radar record shows a thin and rapidly weakening layer of echo at 7000 feet, and a second thin layer at 4000 feet which is presumably stratocumulus. By 1435 there had been a rapid clearance, the only cloud close to the zenith being hooked cirrus (cloud photograph). The echo from this can be seen at 1434 between 24,000 and 28,000 feet. The mixed altostratus and altocumulus was certainly water cloud, for the 0°C level was at 8500 feet on the Aughton sounding at 1130

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* The spots of echo in the pattern (Plate II(*a*)) at heights up to 2000 feet are 'angels'. Plank *et alii*[3] have suggested that these echoes, which can be very numerous at times on vertically-pointing millimetric radars, are caused by 'insects and discontinuities of refractive index'. The authors of the present paper prefers the first of these explanations.

GMT. A slight inversion was present at 4000 feet, which seems to correspond with the level of the lower layer of weak echo. The temperature at 26,000 feet was −34°C. The winds at 4000 and 7000 feet were west-south-west and generally between 25 and 45 knots, so that the horizontal scale of the echoes below 9000 feet in distance measure is roughly equal to the vertical scale, i.e. they appear true to shape. This would be exactly so if the clouds were moving through the beam with a 36-knot wind.[1]

Plate II(*c*) is echo from thick altostratus. It occurred on 13 August 1962. The observer's report was of an overcast sky with cloud base at about 8000 feet and no lower cloud, and indeed the sky-camera record appears featureless. The radar record is an interesting one. The flame-like appearance above 18,000 feet is probably associated with cirrostratus, which at this time may have had its top above the recorded echo top of 24,000 feet. The tapered form and the marked intensity at these high levels suggests that large ice crystals in considerable quantity were being generated at around 24,000 feet. The temperature at 24,000 feet was −28°C, and the 0°C level was 7500 feet. A smooth fallstreak pattern can be seen in the main-layer echo between 18,000 and 12,000 feet and in fact the gap between two precipitation streaks at 12,000 feet at 1024 can be traced in the original negative continuously down to the base of the echo at 10,000 feet at 1030 GMT. An approximate value for the fall velocity of the precipitation in this layer can be determined from the slope of these streaks.[4]

Assuming a generating level at 24,000 feet, and neglecting vertical air motion, which is likely to be small compared with the particle fall-speeds, a fall velocity of about 1 m/s (3 ft/s) is obtained. This suggests that large ice crystals or snowflakes must have been present, with very rapid evaporation taking place below a cloud base at 10,000 feet (see Stewart[4]).

(iii) *Low cloud detection.*—Plate III shows a gradation of echoes received from cumulus mediocris and cumulus congestus. Because of its small droplet size cumulus humilis was not detectable even at high sensitivity and has not been included. Both Plates III(*a*) and (*b*) were recorded on 12 September 1962 in modified polar air behind a cold front which was moving away south-east and had reached the Belgian coast by 1800 GMT. The wind at 3000 feet was west-north-west 20 knots. Plate III(*a*) shows weak echoes from shallow cumulus mediocris whose base was estimated as 2200 feet. The cloud close to the zenith in the sky-camera record at 1325 has only light shadowing at its base. The echoes are very small, with bases at about 3000 feet, and are barely 1000 feet thick. Quite high sensitivity is needed for their detection.

The cloud photographs show that by 1345 GMT the cumulus clouds were heavier with quite dark bases (Plate III(*b*)). They were reported as 7+/8 cumulus mediocris with base 2200 feet, and the observer considered that some of the heaviest were reaching the congestus stage. The echo at 1343 is similar in character to that at 1327 but it is now about 2500 feet deep, with a well-defined top at 5500 feet and an ill-defined base at 3000 feet. The echo intensity near the top of this cumulus, corrected for range, was 10 decibels stronger than the much weaker echo near the echo base. This indeed was a frequent feature of mediocris echoes. It suggests that the largest droplets probably occur near the cumulus tops.

The echoes even in the few minutes of record of Plate III(*b*) show an interesting sequence, from a simple form at 1343 GMT to one showing a quite detailed structure at 1346, while at 1348 raindrops are clearly falling from the cloud and are lost in the transmitter pulse. It is uncertain if this very weak shower reached the ground; the observer did not report it. It is true that the highest top in this small shower may not have passed through the radar beam, and therefore may not have been recorded, but since the 0°C level at this time was 9000 feet it seems very probable that it was a 'warm' shower.

Echoes from stratocumulus are rather similar to the shallower echoes from cumulus mediocris, as for example in Plate II(*b*) at 1430 GMT when the layer of echo at 4000 feet has the same firm top and diffuse base, though not in as marked a form as in Plate III(*a*). The low cloud at 1430 was recorded as 2/8 stratocumulus at 3000 feet but this dissipated rapidly, in good agreement with the behaviour of the echo pattern. A second example is the continuous layer of echo at 3000 feet in Plate I(*c*), which was from stratocumulus with base reported as 2000 feet. The echo top is again stronger than the base. In the third example of stratocumulus echo, Plate I(*b*), there are two weak layer echoes, one with its top at 3000 feet, the other just detectable at 4000 feet. They merge and intensify, and shallow fallstreaks can be seen in the layer echo at 1605 GMT. It seems likely that droplets approaching 200 microns in diameter were forming. In all these layers the temperatures were higher than 0°C.

There is a suggestion in many of the echoes from stratocumulus and cumulus mediocris, not merely from those illustrated here, that droplet sizes are greater towards the top of the cloud. Singleton and Smith[5] have reported some layer clouds in which this was so, but in general they found that concentrations and droplet sizes were very variable. Durbin[6] also found from aircraft measurements that the size of the droplets in cumulus clouds tended to increase with height, with mean volume diameters of about 5 to 10 microns near cloud base, but 20 to 25 microns near the cloud tops. Variations in the vertical should be more reliably observed by millimetric radar than by an aircraft which is unlikely to penetrate precisely the same cloud when obtaining data at different levels. Radar indeed shows how rapid are the changes in cloud composition in the horizontal, even in an apparently uniform overcast layer, and these changes must affect aircraft measurements.

Plate III(*c*) shows the much more intense echoes from active cumulus congestus. This was on 11 July 1962, when a low-pressure area was centred over the British Isles, and outbreaks of rain occurred, locally heavy and with thunder, notably in East Anglia. A thunderstorm was reported at Ross-on-Wye only 17 miles from the radar site at Malvern. Rain was just commencing when the cloud photograph was taken at 1000 GMT. The cloud was reported as a mixture of cumulus congestus and cumulus mediocris with its main base at 2500 feet, but with some cloud fragments beneath. The dark patches on the cloud photographs at 1005 and 1010 GMT are caused by water drops on the lens, but those at 1000 are dark cloud bases. The rain was moderate at 1005, but by 1010 the edge of the darker cloud mass had almost cleared the zenith, and the sun can be seen weakly. The cloud mass seems to have passed squarely over the radar, though it is uncertain if the highest tops

passed through the beam. The echo is chaotic in appearance. Fallstreaks, where they can be detected, are nowhere consistent, probably because of varying updraughts and downdraughts and of varying local winds. Only from about 5000 to 8000 feet between 1007 and 1010 GMT is there any uniformity of slope, suggesting that this section of the shower cloud may be decaying and may contain more uniformly falling precipitation. The air temperature at 19,000 feet was −23°C, and the 0°C level was at 6000 feet, but no bright-band effect could be seen in this shower when examined at reduced gain.

The weakening of the echo above 9000 feet at 1008 GMT is an effect of attenuation, due to the strong absorption of energy by heavy rain at lower levels. Attenuation can be a very important effect at millimetric wavelengths.[1] The quite sudden increase in echo intensity at 1008½ GMT occurs when the heavier rain in the lower layers clears the beam. Attenuation effects earlier in the shower may well have been more insidious, possibly entirely preventing detection of precipitation at the higher levels in the shower.

(iv) *Detection of cumulonimbus.*—The final illustration, Plate IV, is of the echo pattern from a cumulonimbus which was recorded later on the same day as the cumulus congestus of Plate III(*c*). No claim can be made that this is typical of cumulonimbus because far too few have passed over the radar when it was in operation, and they were usually the edges of storms. The pattern suggests a most complex structure. It was not a particularly active cumulonimbus ; there were no reports of thunder or of hail. There was a well-defined bright band at 6000 feet for most of the 20 minutes taken by the cloud to pass over the radar, coinciding almost exactly with the 6000-foot height marker. It suggests that this was a decaying stage of cumulonimbus, with precipitation falling mainly as snow from higher levels.

There is no doubt that much of the pattern of high-level echo before 1240 GMT has been lost because of rain attenuation, and it is unlikely that the true cloud top or precipitation top was being recorded in this region. The vertical shadowing of the pattern at 1232½, 1236 and 1238 GMT is a more obvious effect of attenuation. It is only after 1240, when the rainfall at the ground had become very light, that the high-level echo becomes strong, providing supporting evidence that before this time much is being lost. Further evidence that echo has been lost is shown by the brightening of the height and time marking lines, e.g. at 1235 GMT at levels up to 23,000 feet, which suggests that there was precipitation at least up to this level. In the original negative, weak echo at 1242 GMT can in fact be seen at 25,000 feet, only a little below tropopause level at 27,000 feet. The air temperature at 25,000 feet at this time was −40°C.

The most striking feature of this pattern is the chaos at the higher levels. It is hard to believe that the detail in patterns of this kind will ever be fully understood.

Acknowledgements.—The Meteorological Office is indebted to the Chief Scientist, Ministry of Aviation and to the Royal Radar Establishment, Malvern, for the opportunity to use this radar for meteorological studies.

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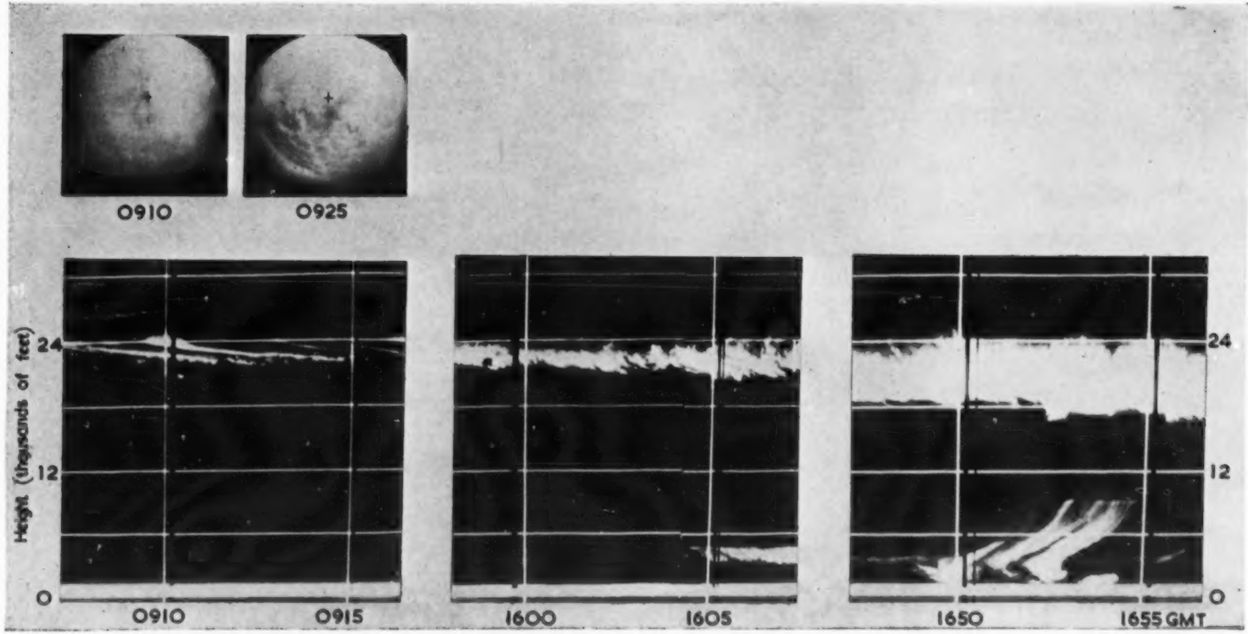
FURTHER DISCUSSION ON THE OBSERVATIONS OF CLOUD WITH 8·6-MILLIMETRE RADAR

By J. B. STEWART, B.Sc., D.I.C.

The record obtained from the vertically-pointing millimetric radar on 13 August 1962, is described by Harper[1] and is particularly interesting because it shows a cloud which has a sharply-defined base even though there is precipitation falling into it from the cloud above (Plate II(*c*) shows part of the record). Also it is unusual in these circumstances for the cloud base to remain at virtually the same height—it only descended 1150 feet in the 65 minutes that the radar was operating. These observations can be explained either by the presence of a sufficiently strong updraught to support the precipitation particles or by the evaporation of these particles beneath the cloud. Though neither of these explanations can be completely ruled out, it seems from the following evidence that the latter is more likely.

Throughout 13 August there was a complex warm-front system nearly stationary over southern England which gave layers of cloud at about 10,000 – 13,000 ft, 16,000 – 18,000 ft and 25,000 ft above Malvern. An aerological cross-section through Malvern at approximately right angles to the front at 1200 GMT showed that the temperature at the height of the upper cloud was about – 28°C, so that it is reasonably certain that the precipitation shown by the fallstreaks was composed of ice crystals. However it is quite likely that the lower layers of cloud with temperatures of – 15°C and – 5°C contained super-cooled water drops, so that the ice crystals would become rimed as they fell through these clouds. The 0°C level at Malvern appeared from the cross-section to be at a height of 7500 ft, that is below the lowest layer of cloud, and this is confirmed by the radar traces which did not show any melting band. The Aughton radiosonde ascent showed that the air between the lower surface of the front and a height of 5000 ft was very dry — relative humidity only about 30 per cent with respect to ice.

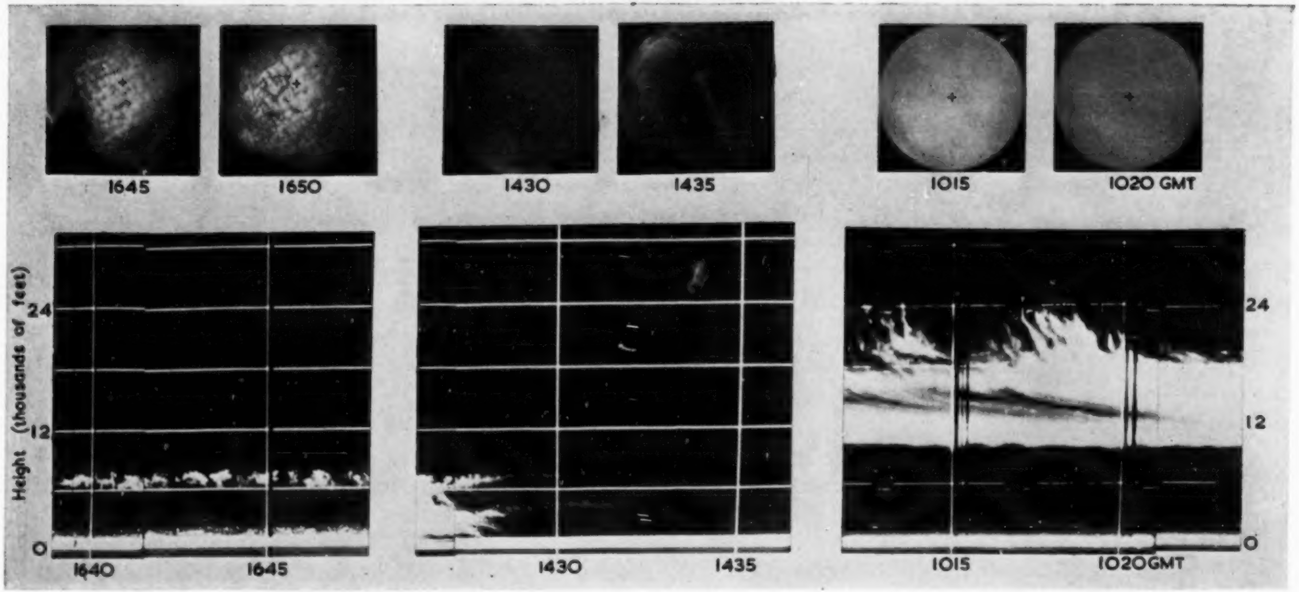
If vertical motion alone was responsible for the base of the radar echo remaining at nearly the same height, then the updraught must have been approximately equal to the fall-speed of the precipitation particles. From the slope of the precipitation fallstreaks it is possible to calculate the fall-speeds of the particles relative to the ground, if the wind profile is known.



(*a*) Cirrus, 24 September 1962 (*b*) Cirrus and cirrostratus, 31 October 1961 (*c*) Dense cirrostratus, 31 October 1961

PLATE I—EXAMPLES OF THE DETECTION OF HIGH CLOUD ON THE HEIGHT–TIME RECORD FROM AN 8·6-mm VERTICALLY-POINTING RADAR, WITH SIMULTANEOUS SKY-CAMERA RECORDS WHEN AVAILABLE

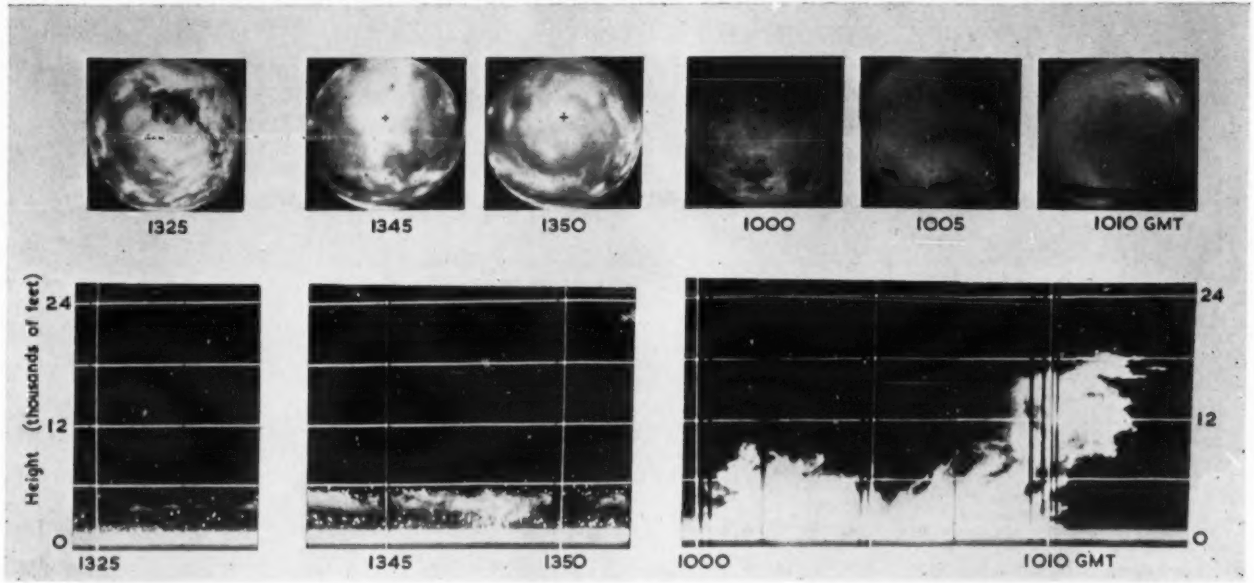
See page 106.



(*a*) Altocumulus, 18 September 1962 (*b*) Altostratus and altocumulus, 1 November 1961 (*c*) Thick altostratus, 13 August 1962

PLATE II—EXAMPLES OF THE DETECTION OF MEDIUM CLOUD ON THE HEIGHT–TIME RECORD FROM AN 8·6-mm VERTICALLY-POINTING RADAR, WITH SIMULTANEOUS SKY-CAMERA RECORDS

See page 108.



(*a*) Cumulus mediocris, 12 September 1962 (*b*) Cumulus mediocris, 12 September 1962 (*c*) Cumulus congestus, 11 July 1962 Cumulonimbus, 11 July 1962

PLATE III—EXAMPLES OF THE DETECTION OF CUMULUS MEDIOCRIS AND CUMULUS CONGESTUS ON THE HEIGHT–TIME RECORD FROM AN 8·6-mm VERTICALLY-POINTING RADAR, WITH SIMULTANEOUS SKY-CAMERA RECORDS

See page 109.

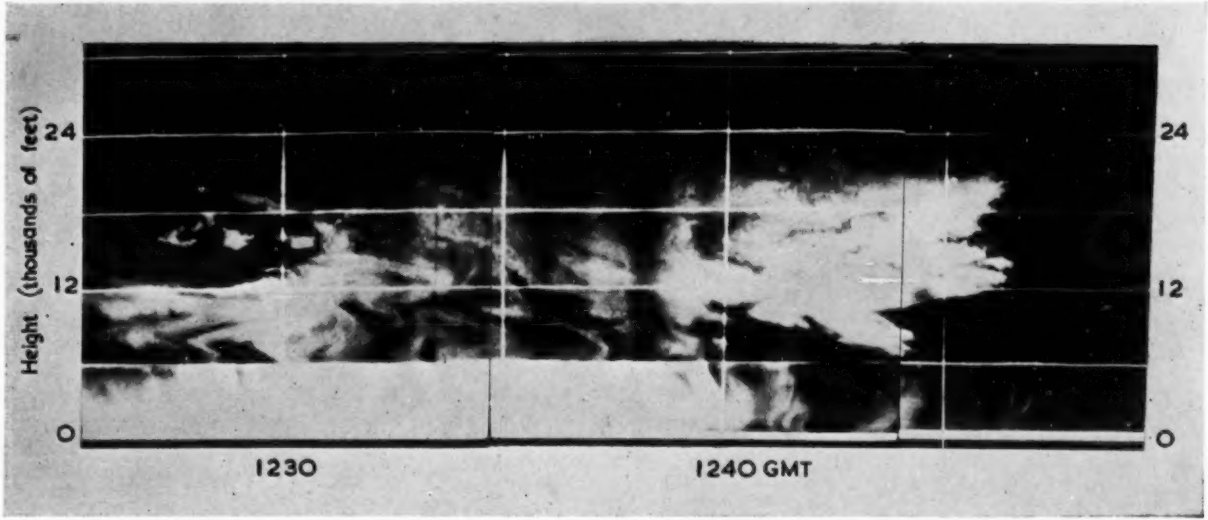


PLATE IV — A PATTERN OF A CUMULONIMBUS RECORDED ON THE HEIGHT–TIME RECORD FROM AN 8·6-mm VERTICALLY-POINTING RADAR

See page 111.

Unfortunately the available upper-wind measurements are not truly representative of the Malvern area, so that accurate calculations cannot be made. However it can be estimated that the fall-speeds were between 2 and 6 ft/second (s) with 4 ft/s as the most likely value. These estimates agree reasonably with the measurements by other workers, for example Langleben[2] who found that the maximum fall-speed for solid precipitation, other than hailstones, was about 5 ft/s. So to maintain the echo base at the observed height, the updraught would need to have been at least 2 ft/s at the base, and then to have decreased to nearly zero within about 1000 ft above the base, since the fallstreaks can be followed down to the echo base. The height of the base varied very little during the period that the radar was operating, which implies that the strength of the updraught would need to have been nearly constant. Also the updraught must have continued for many hours, since if this was the only effect which was preventing the precipitation reaching the ground, then any marked decrease in the updraught strength should have resulted in rain being reported in the Malvern area and none was reported at Pershore, which is only a few miles away, until 1340 GMT, even though the warm front and its associated clouds had certainly been over the area since 1000 GMT and probably for much longer.

If the alternative explanation, that the observed features of the cloud were caused by evaporation of the precipitation, is correct, then it should be possible from the radar traces to detect the layer through which evaporation was taking place and to show that evaporation was sufficiently rapid for the precipitation particles to be undetectable by the radar after falling this distance. The original radar pictures — not however the prints — show that the intensity of the echo decreased towards its base and the traces obtained with the radar sensitivity reduced show that this layer of decreasing echo strength was 600 to 1300 ft deep. This decrease in echo strength can only be attributed to the evaporation of the precipitation. To determine whether this distance would be sufficient to evaporate the ice crystals to such a size that they could not be detected by the radar, similar calculations to those of Stewart[3] were carried out using appropriate values for the constants. For an estimate of the mass of the ice crystals before evaporation began, the results of Langleben[2] were used. He had found that rimed dendritic crystals, which had fall-speeds of 3 to 4 ft/s, had masses of $\frac{1}{2}$ to $1\frac{1}{2}$ milligrams. With these values and a relative humidity with respect to ice of 30 per cent beneath the cloud, the distance was found to be 1000 to 2000 ft, which is in reasonable agreement with the observed distance. As the evaporation of the precipitation continued, it would have progressively saturated the air beneath the cloud and so lowered the cloud base. It is therefore necessary to show that the slow rate of descent, which was observed by the radar, is consistent with a reasonable rate of precipitation from the upper cloud. Over the period of 65 minutes that the radar was operating, the echo base descended 1150 ft and from this it can be calculated that, since the relative humidity of the air beneath the cloud was only 30 per cent with respect to ice, the rate of precipitation must have been as high as 1·0 millimetres/hour.

It can be concluded from these calculations that the sharply defined base of the cloud and its slow descent can be explained by the evaporation of the precipitation in the very dry air beneath the cloud. This case again shows

that a cloud with its base above the 0°C level can produce moderate precipitation for many hours before any reaches the ground, as has been previously demonstrated by Stewart.[3]

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FURTHER WORK ON OBJECTIVE FORECASTING OF VISIBILITY

By VALERIE D. JACK

Introduction.—Objective methods of forecasting are methods which do not involve personal judgement; they have been considered in the Meteorological Office for a number of years (Freeman[1]), but ideas involving rigorous statistical methods were not practicable until the advent of the electronic computer. Diagrams based on the Freeman[2] objective method were produced in 1958 for predicting visibility at London (Heathrow) Airport. These were issued to Heathrow for testing during the months of November, December and January of the winters 1958/59 and 1959/60. Similar diagrams for Manchester Airport were issued in 1959 to be tested during the winter of 1959/60. The results of these tests (Freeman[2]) were encouraging and it was decided that further diagrams should be computed for, in the first instance, Heathrow and that they should be based on a larger amount of data to provide three-hour and six-hour forecasts from each of the eight synoptic hours. This note describes the production of diagrams to give three-hour and six-hour forecasts from most synoptic hours for most of the six winter months October to March, and includes tests of the results obtained from five of the diagrams.

Correlation coefficients (r) were calculated between the forecast visibility and the visibility which actually occurred at the time for which the forecast was made. The formula used was

$$r^2 = 1 - (SE/SD)^2$$

where SD was the standard deviation of the visibility at the time for which the forecast was made and SE (here called standard error) was obtained by finding the root mean square of the differences between the forecast visibility and that which actually occurred. Units were according to a special visibility scale described by Freeman.[1] The scale consisted of 32 steps, the latter part of the scale being approximately logarithmic, while the code figures 0–15 gave the visibility up to 2000 yd in the ranges required for operational forecasting. Thus additional emphasis was given to the lower ranges.

Figure 1 is reproduced to show the mehtod of using the composite diagrams. The top left-hand section is entered with the appropriate value of the first predictor and the pecked line on the diagram indicates how the successive sections are entered and how the forecast is finally read from the scale on the last section.

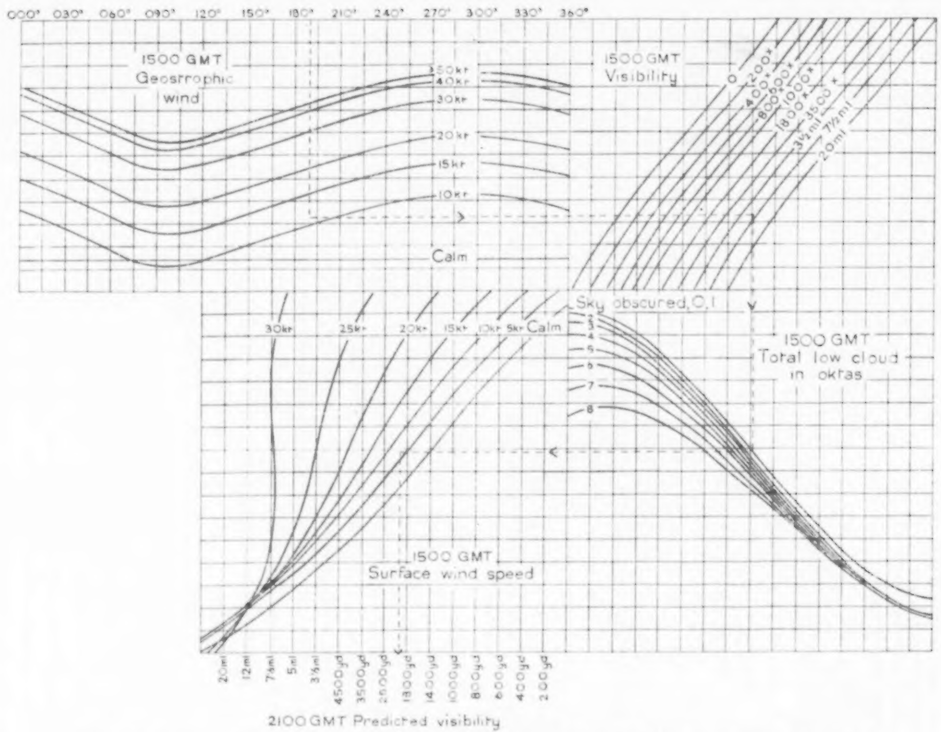

FIGURE 1—VISIBILITY PREDICTION DIAGRAM FOR LONDON (HEATHROW) AIRPORT, OCTOBER TO MARCH

The visibility at 2100 GMT is forecast from predictors at 1500 GMT.
The pecked line shows how, for example, a forecast visibility of 2000 yd is obtained from the following predictors : geostrophic wind 190°, 11 kt ; visibility 6 miles (ml) ; total cloud 0 ; surface wind speed 7kt.

Selection of parameters.—In Freeman's preliminary tests up to 25 different parameters were considered. However, many of these were incorporated in other parameters ; for example, wind shear can be indicated by using geostrophic and surface winds ; and some parameters, e.g. hydrolapse, involved much data extraction. It was therefore decided to examine the 10 parameters which previously had shown most promise amongst the original 25 parameters. The 10 parameters were :

Geostrophic wind direction	Temperature
Geostrophic wind speed	Past weather/present weather*
Surface wind direction*	Temperature lapse rate*
Surface wind speed	Total cloud amount
Visibility	Total low cloud amount

*Parameters not used in any of the five diagrams used for the tests.

Special notes are listed under the following headings :

Wind.—In the original tests it was found that the geostrophic wind at the time of the forecast was more highly correlated with the visibility at the end of the forecast period than was the surface wind. However, geostrophic winds are neither recorded nor are they always easily available, and measuring a large number from working charts is time-consuming and may not be particularly reliable. A computer programme was therefore written which evaluated geostrophic winds from a network of mean-sea-level pressures and these calculated winds were compared with measured geostrophic winds over a test period (Freeman[3]). In general the winds produced by the computer appeared to be more reliable than those which were measured from the charts, and all the geostrophic winds used for the diagrams are now calculated by the computer methods.

All wind directions are in tens of degrees with north as 360°. For the geostrophic winds, light winds and calms were dealt with by making the direction zero when the speed was below a certain strength, and these observations were considered in a separate class. Wind speeds of <7, <9 and <10 knots were tested as criteria for defining the class of light winds. Correlation results with a wind speed criterion of <7 knots were not so good as with the other two criteria which gave such similar results that the diagram could be produced with a wind speed criterion of either <9 or <10 knots.

A class of light winds can also be used when examining surface wind direction as a parameter. It was found that the best wind speed criterion for such a class was lower than that for geostrophic winds. Wind direction is not easy to use as a parameter except in the first part of the composite diagram. After geostrophic wind direction has been used the surface wind direction does not give correlation results good enough to justify its use in preference to other parameters which are more easily used.

Temperature.—Data tapes were received from the Meteorological Office Punched Card Installation in degrees Fahrenheit and the data were used in this form. Curves were eventually drawn on the forecasting diagrams at nine-degree intervals on the Fahrenheit scale and renumbered as five-degree intervals on the Celsius temperature scale.

Past weather / present weather.—Correlation coefficients (between forecast and actual visibility) using past weather to forecast visibility three or six hours later were calculated during the earlier experiments and were encouraging but data tapes for past weather were available only from 1957. As tapes

for present weather were available for a much longer period it was decided to try this parameter instead. Although the correlation coefficients using present weather as a forecasting predictor were also fairly good ($\simeq 0{\cdot}65$), no improvements in the correlation coefficients resulted when the visibility was forecast by using a number of predicting parameters to which was added present weather. This may be because the relevant physical properties of the present weather are represented in the other parameters. Hence no weather parameter was used directly in any of the diagrams produced.

Temperature lapse rate.—This is one of the parameters which can be defined in several ways, very few of which are immediately available from existing recorded data. In the original tests the lapse rate in the lowest 50 mb showed promise, coming eighth best in the list of parameters tested. The data were extracted from ascents plotted on tephigrams, and consisted of the difference between the temperature at the surface and the temperature at 50 mb above the surface. As this method was very laborious it was decided in the later diagrams to try an alternative lapse rate which could be extracted by computer from data available on punched cards. This lapse rate was defined by

$$1000(T_{\text{surf}} - T_{900})/H_{900}$$

where T_{surf} is the Crawley surface temperature in degrees Fahrenheit,

T_{900} is the Crawley 900 mb temperature in degrees Fahrenheit, and

H_{900} is the 900 mb height in feet.

A correlation test was carried out with these data but the results were not encouraging. It was therefrore decided not to use lapse rate as a predictor at this stage, but it is hoped that there will be time to examine this parameter more fully later.

Cloud.—Data tapes for total cloud amount and total low cloud amount were obtained from the Meteorological Office Punched Card Installation.

Method of producing diagrams.—As this has been described in detail by Freeman[2] it is necessary to mention only a few points. It was found that graphs produced by using polynomial quintic equations were over-complicated and this method often tried to fit anomalous observations. Quartic equations were used to produce the first figure of each diagram and thereafter cubic equations were used. These gave simpler graphs than the quartic equations, with comparable correlation coefficients.

Production of the diagrams.—The diagrams were produced from 13 years' data from winters 1949/50 up to and including 1961/62. These years include several during which fog in the ranges 1090 – 440 yards has been on the decline in the Heathrow area because of the Clean Air Act (Wiggett[4]).

All winter months October to March inclusive were used, firstly as two blocks, November, December, January (NDJ) and October, February, March (OFM), and then, if the results of these blocks were similar, all together (Table I). The correlation coefficients of the NDJ blocks were generally better than those of the OFM blocks. The two results marked with daggers in Table I, were not considered good enough for issue to Heathrow for operational use.

Diagrams based on observations made entirely during hours of darkness had not previously been produced and it is interesting to note that once the geostrophic wind speed and direction and visibility had been used as predictors

TABLE I—DETAILS OF DIAGRAMS NOW AVAILABLE FOR FORECASTING VISIBILITY AT HEATHROW (BASED ON THE PERIOD 1949–62)

Time of predictor data	Forecast for a time 3 hours ahead: Number of predictors	Groups of months available	SD	(SE)	r	Forecast for a time 6 hours ahead: Number of predictors	Groups of months available	SD	(SE)	r
GMT										
0000	3	ONDJFM	7·7	3·5	0·89	4	ONDJFM	7·8	4·5	0·82
0300*	3	ONDJFM	7·8	3·5	0·90	–				
0600	4	ONDJFM	7·8	3·8	0·87	4	NDJ	7·3	4·2	0·82
						5	OFM†	5·9	4·1	0·72
0900	5	NDJ	7·3	3·5	0·88	4	NDJ	6·7	4·1	0·79
	5	OFM	5·9	3·3	0·83	4	OFM†	5·1	3·8	0·68
1200	4	ONDJFM	6·1	3·2	0·85	4	ONDJFM	6·3	3·8	0·80
1500	5	ONDJFM	6·3	3·2	0·86	5	ONDJFM	7·1	4·2	0·80
1800‡	–					–				
2100	3	ONDJFM	7·5	3·5	0·89	4	ONDJFM	7·7	4·5	0·81

SD and (SE) are in units of special visibility scale.[3]
SD = Standard deviation of visibility at the time for which the forecast was made.
(SE) = Standard error as described in the text.
r = Correlation coefficient between the forecast visibility and that which actually occurred.
ONDJFM are initial letters of the winter months October to March.
*Diagrams have not yet been produced for forecast time 6 hours ahead.
†Not issued for operational use.
‡Diagrams have not yet been produced for forecast time 3 hours or 6 hours ahead.

any other parameter made very little improvement on either the standard error or the correlation coefficient. Table II(*a*) shows this effect for a three-hour forecast from 2100 GMT data. A tendency towards similar results can be seen in Freeman's results[2] for forecasts based on 0600 GMT data (Table II(*b*)).

TABLE II (*a*)—STATISTICS OF CORRELATION BETWEEN HEATHROW ACTUAL VISIBILITY AT 0000 GMT AND THE FORECAST VISIBILITY FOR 0000 GMT BASED ON VARIOUS PREDICTORS AT 2100 GMT*

2100 GMT predictor	(SE)	r
Direction and speed of geostrophic wind (D_v)	4·9	0·75
D_v + visibility (V)	3·5	0·89
$D_v + V$ + temperature	3·5	0·89
$D_v + V$ + surface wind speed	3·4	0·89
$D_v + V$ + total low cloud	3·4	0·89
$D_v + V$ + total cloud	3·4	0·89

*For the period 1949–62. SD for 0000 GMT visibility = 7·5.
For SD, (SE) and r see Table I.

TABLE II (*b*)—STATISTICS OF CORRELATION BETWEEN HEATHROW ACTUAL VISIBILITY AT 0600 GMT AND THE FORECAST VISIBILITY FOR 0900 GMT BASED ON VARIOUS PREDICTORS AT 0600 GMT* (AFTER FREEMAN[2])

0600 GMT predictor	(SE)	r
Direction and speed of geostrophic wind (D_v)	5·2	0·77
D_v + visibility (V)	3·9	0·88
$D_v + V$ + temperature (T)	3·7	0·89
$D_v + V + T$ + surface wind speed	3·7	0·89

*For the period November 1949–January 1957. SD for 0900 GMT visibility = 8·2.
For SD, (SE) and r see Table I.

Results.—Five diagrams were available at Heathrow from the beginning of October 1964, and forecasters were asked to keep a record of results obtained from these during the winter 1964/65. Tests were also carried out at Meteorological Office Headquarters, Bracknell, using independent data from winters 1962/63 and 1963/64.

TABLE III—COMPARISON OF RESULTS FROM OBJECTIVE AND SUBJECTIVE FORECASTS

Type of forecast	3-hour forecast from 0600 GMT data for ONDJFM			6-hour forecast from 0600 GMT data for NDJ			3-hour forecast from 0900 GMT data for NDJ			3-hour forecast from 2100 GMT data for ONDJFM			6-hour forecast from 2100 GMT data for ONDJFM		
	SD	(*SE*)	*r*	*SD*	(*SE*)	*r*	*SD*	(*SE*)	*r*	*SD*	(*SE*)	*r*	*SD*	(*SE*)	*r*
Subjective (test on Heathrow TAF's winter 1964/65)	6·8	4·3	0·78	6·3	3·6	0·82	6·3	3·3	0·85	6·5	3·4	0·85	6·9	4·4	0·78
Objective (test on independent data winter 1964/65)	6·8	3·7	0·84	6·3	3·5	0·85	6·3	3·1	0·87	6·5	3·1	0·88	6·9	4·3	0·78
Objective (test on independent data winters 1962/63 and 1963/64)	7·3	3·7	0·86	6·9	4·1	0·80	6·9	3·9	0·83	7·4	3·4	0·89	7·9	4·8	0·79
Objective (dependent data period 1949–62)	7·8	3·8	0·87	7·3	4·2	0·82	7·3	3·5	0·88	7·5	3·5	0·89	7·7	4·5	0·81

Note : for definitions of *SD*, (*SE*) and *r* see Table I.

The results of these tests at Heathrow and at Bracknell are shown in Table III. Subjective forecasts for the time of the objective forecasts were obtained by interpolation from routine TAF's (coded terminal aerodrome forecasts), due allowance being made for any changes forecast during the period of validity of the TAF.

In all cases the objective forecasts from independent data for winter 1964/65 gave slightly better results than the TAF forecasts for the same period. This is encouraging, but as the amount of data was so small the results cannot be counted as conclusive. However further tests of these five diagrams and of nine additional diagrams are planned for winter 1965/66. The combined data for 1964/65 and 1965/66 should allow firmer conclusions to be drawn.

The parameters used in the five diagrams tested, together with the resulting standard errors and correlation coefficients at each stage are shown in Table IV.

TABLE IV—PREDICTORS USED IN THE FIVE TEST DIAGRAMS FOR FORECASTING VISIBILITY AT HEATHROW (BASED ON THE PERIOD 1949–62)

Time of forecast data GMT	*SD*	Time of predictor GMT		Predictor*	(*SE*)	
0900	7·8	0600	(i)	geostrophic wind	5·4	0·72
			(ii)	visibility	4·0	0·86
			(iii)	temperature	3·8	0·87
1200	7·3	0900	(i)	geostrophic wind	5·0	0·73
			(ii)	visibility	3·6	0·87
			(iii)	temperature	3·6	0·87
			(iv)	total low cloud	3·5	0·88
0000	7·5	2100	(i)	geostrophic wind	4·9	0·75
			(ii)	visibility	3·5	0·89
1200	7·3	0600	(i)	geostrophic wind	4·9	0·74
			(ii)	visibility	4·3	0·81
			(iii)	temperature	4·2	0·82
0300	7·7	2100	(i)	geostrophic wind	5·3	0·72
			(ii)	visibility	4·6	0·80
			(iii)	total low cloud	4·5	0·81

For *SD*, (*SE*) and *r* see Table I

*The Roman number indicates the stage in the predictor diagram. At each stage the predictor listed is added to the ones used in the previous stage. The correlations show the improvement obtained as more stages are used.

The five diagrams for Heathrow were produced first for the following specific reasons:

(i) The three-hour and six-hour forecast diagrams from 0600 GMT data were chosen so that they could be compared with the earlier experimental diagrams produced by Freeman.[2] There was little difference between the new six-hour forecast diagram and the earlier six-hour forecast diagram; each was for the three months November, December, January. The standard error and the correlation coefficient obtained by using the new three-hour forecast diagram were not quite as good as those obtained from the earlier diagram, but the new diagram is for the six winter months October to March whereas the earlier diagram was for only the three months November, December and January. In addition both of the new diagrams use one less parameter than the earlier experimental diagrams and consequently are a little easier and quicker to use.

(ii) The three-hour and six-hour forecast diagrams from 2100 GMT data were chosen to give forecasts during the night as this had not previously been done. The results obtained by using these diagrams were reasonably satisfactory and similar to those obtained for forecasts during the day (see Table III).

(iii) The three-hour forecast from 0900 GMT data was chosen as this was a useful time for aviation purposes. From Table III it can be seen that for the winter 1964/65 the objective forecast was better than the subjective forecast though it must be remembered that only about 90 pairs of forecasts were compared.

Further plans.—Work has already started on preparing data for the production of diagrams for Heathrow for the summer months. It is hoped that some of these months will combine with some of the winter months (e.g. using February, March and April together) to produce more promising results than those shown in Table I.

When diagrams have been produced for Heathrow to give three-hour and six-hour forecasts from each of the eight synoptic hours for every month it is hoped that diagrams can be produced for other important aerodromes in the British Isles. Further in the future is the possibility of extending this method of objective forecasting to predict other weather elements.

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551.574.13:551.575.1

GLACIATION OF WATER FOG AND A TEMPORARY IMPROVEMENT IN VISIBILITY AT SHAWBURY

By D. J. GEORGE and R. HILL

At Shawbury at 0915 GMT on 3 February 1965, tiny rounded opaque ice crystals were observed to be falling; the sky was obscured at the time and the horizontal visibility was 50 yards. The crystals were just visible when viewed against black cloth (similar to 'diamond dust' observed in the Antarctic by the first-named author) and gradually grew in size to become ice needles of length 1 to 2 millimetres by 0928 GMT, covering the ground with a thin white coating. The visibility had meantime increased to 250 to 300 yards to the north-east and about 150 yards to the south-west, and the sky became visible so that a thin layer of upper cloud covering 5/8 of the sky could be seen. The precipitation ceased by 0935 GMT and the visibility then fell quickly to 80 to 110 yards, and the sky became obscured again. The fog cleared by 1130 GMT.

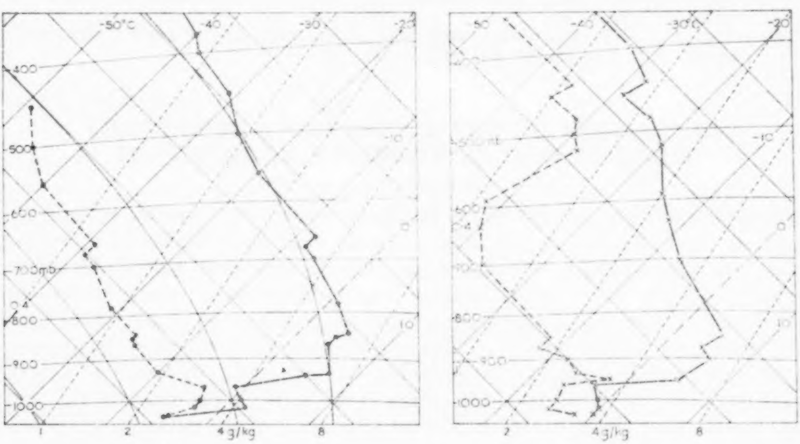
The fog top was reported as being below the tops of the local hills (400 to 680 feet above mean sea level) by several members of the public between 0600 and 0800 GMT. The minimum temperature overnight was −6·3°C, and the grass minimum temperature was −10·8°C. Negative depressions of the

ice bulb (indicating supersaturation of the air with respect to an ice surface) had occurred on several occasions after the fog formed, as shown in Table I.

TABLE I—HOURLY READINGS AT SHAWBURY

Time GMT	00	01	02	03	04	05	06	07	08	09	10
Screen temperature (°C)	-4.8	-5.0	-6.0	-5.5	-5.6	-5.2	-5.0	-5.0	-5.5	-5.2	-5.0
Ice bulb (°C)	-4.7	-4.9	-6.1	-5.4	-5.4	-5.1	-4.9	-5.1	-5.4	-5.2	-5.0
R.H. with respect to water (per cent)	98	98	92	98	100	98	98	93	98	95	96
Dew-point (°C)	-5.1	-5.3	-7.1	-5.9	-5.6	-5.5	-5.3	-6.0	-5.8	-5.9	-5.6
R.H. with respect to ice (per cent)	103	102	98	103	104	102	102	98	102	100	100
Frost-point (°C)	-4.5	-4.7	-6.3	-5.2	-5.0	-4.9	-4.7	-5.3	-5.2	-5.2	-5.0
Visibility (yards)	330	280	220	250	30	30	50	80	80	50	80
Surface wind (degrees/knots)	Calm	Calm	Calm	Calm	Calm	Calm	Calm	240/3	240/3	Calm	Calm

Synoptic situation.—At the time the area was under the influence of a slow-moving anticyclone centred over western Scotland, with a ridge of high pressure extending over southern England. Radiation fog had formed at a temperature of −5°C around midnight, and had thickened slowly, depositing rime. The upper air sounding for Aughton (near Liverpool), considered representative of the area, showed a subsidence inversion with base about 960 millibars and dry air above and a night cooling inversion at low levels (Figure 1).



(*a*) 0000 GMT

· ———— · Temperature
· – – – – – · Dew-point

(*b*) 1200 GMT

x ———— x Temperature
x – – – – – x Dew-point

FIGURE 1—UPPER AIR SOUNDINGS AT 0000 AND 1200 GMT AT AUGHTON ON 3 FEBRUARY 1965

The surface temperature and dew-point at 0900 GMT at Shawbury has been superimposed on the 0000 GMT sounding.

Discussion.—On the evidence of the moist layer around 18,000 feet on the Aughton upper air sounding, it is probable that the layer cloud observed was about 18,000 feet and therefore it is fairly certain that the ice needles fell from the supercooled water fog. The surface temperature at the time of the precipitation was within the range of –3 to –8°C given by Mason[1] for the origin of needle-shaped crystals. The water droplets in the fog having been initially seeded with ice crystals (perhaps by slight turbulence around trees and hangars, and contact with rime accretion on trees and objects), further growth of ice crystals took place at the expense of the surrounding atmosphere which was saturated or perhaps slightly supersaturated with respect to an ice surface whilst visibility improved as the water droplets in the fog evaporated and the ice crystals fell out. The process is probably similar to that which produces fallstreak holes in a cloud sheet aloft composed of supercooled water droplets.[2]

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551.501.9:551.506.2(414)

THE EDINBURGH METEOROLOGICAL OBSERVER 1731-36

By H. J. MATTHEWS

Weather records of one sort or another have been kept since the times of the earliest civilizations, but they were necessarily descriptive until the invention of the barometer and thermometer about the mid-seventeenth century. Even then many years were spent in finding out how these instruments should be correctly used. An examination of *World Weather Records*[1] indicates that regular series of instrumental observations, which can be regarded as homogeneous with those of today, did not begin until the mid-eighteenth century.

The records for Edinburgh embrace the periods June 1731–May 1736 and 1764 to date for temperature, 1769 to date for pressure and 1770–76, 1780–June 1781 and 1785 to date for rainfall. These periods constitute the longest series of homogeneous observations — for all three elements — listed in *World Weather Records*. The collection, reduction and standardization of the old Edinburgh records were undertaken by R. C. Mossman[2] towards the end of the last century. The earliest series of observations he was able to trace were those for the period 1731–36 published in the six volumes of *Medical Essays and Observations*.[3] The first volume includes a brief description of Edinburgh at that time and a detailed account of the instruments used and their general exposure. Until recently the identities of the meteorological observer and the members of the Society responsible for the publication of the essays were unknown. Mossman quoted Forbes's[4] belief that the observer was an unknown medical man resident in the vicinity of the present City Chambers.

As a result of publicity given to this series of observations in the Meteorological Office display at the recent Battle of Britain Exhibition in Edinburgh, Mr. R. W. Munro (Hon. Editor *Clan Munro Magazine*) wrote to the Meteorological Office (Edinburgh) identifying the unknown observer as a William Monro, Bookseller. The identification was based on an article by

H. D. Erlam[5] that was itself based on a manuscript in Professor Alexander Monro's proven handwriting.[6] Despite the evidence of the handwriting there exist some doubts if the manuscript is truly an autobiography, but it does identify the members of the Society '... to which Monro (primus) was secretary ; who prepared the instruments for the Register of the Weather and committed the care of making the observations to his regular and accurate friend William Monro, Bookseller' — they were, in fact, related.

Short[7] credits the observations to Dr. Andrew Plummer. This may be because the original society, of which Plummer was a member, disbanded about 1737 and was replaced by one of a more general nature — The Philosophical Society of Edinburgh. Professor Monro, owing to ill health, was unable to take up the proffered post of Secretary to the Natural Science section and the post was filled by Plummer on Monro's recommendation.

It is difficult to understand why there should be such a gap, 1736–64, in the Edinburgh records as the city abounded with able men during this period. No doubt the political troubles prior to the 1745 insurrection, and its aftermath, contributed to this hiatus. Even so, great developments took place in other branches of science, in medicine and in literature during this period so that the lack of meteorological observations is rather surprising after the promising start in 1731. Efforts have been made to trace observations that might fill the gap, but so far with no success.

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REVIEWS

Barrier waves in the atmosphere by Sh. A. Musaelyan (translated from Russian). $9\frac{1}{2}$ in$\times 6\frac{3}{4}$ in, pp. viii + 112, *illus.*, Israel Program for Scientific Translations, Jerusalem. Oldbourne Press, 1–5 Portpool Lane, London, E.C.1, 1964. Price : 45*s*.

Qualitatively most of the phenomena associated with airflow over mountains are understood or, at least, known about. For some of them there is a precise mathematical theory ; for others there is still only a geographer's description. Many writers fall down by implying that their theory is applicable to phenomena which are quite beyond it or by generalizing 'conclusions' drawn from observations in a rather restricted field.

Authors often seem aware of only some of the very wide variety of phenomena known. This author bases his book on such work as he is familiar with rather

than on the subject matter as a whole, but writes rather as if his review were complete. Theory, observation and speculation are not well distinguished. This is particularly apparent when he describes Förchtgott's descriptive classification of flow types — a stimulating effort when written but now out of date — for he has tried to formulate a mechanical explanation of the classification as if it were a correct theory. As a result we find a kind of mumbo-jumbo which the Israeli translator (into English) seems to understand even less clearly than the Russian author, and it is not really worth trying to sort it out.

Research in the U.S.S.R. seems to have followed much the same basic lines as elsewhere, but with different emphasis : for example, the Russian scientists were for a time obsessed with the possibility of nodal (horizontal) surfaces in wave flow. They do not seem to acknowledge the fundamental work of Kelvin, Rayleigh and Lamb on lee waves, and also seem unaware that there has ever been a problem in the boundary condition at great height. The hydrostatic assumption is used unnecessarily, and the effects of the earth's rotation introduced in a very haphazard way. The significance of the large-amplitude solutions (e.g. of Long and Yih) which are nevertheless linear seems unnoticed, and there is no reference to post-war Scandinavian papers in the text although one or two are listed.

From the practical viewpoint the treatment of altimeter errors is unnecessary, because the winds which accompany them are, of course, far more important to an aircraft pilot. The first appendix is a rather unsatisfactory enlargement of the theoretical part of the introduction, the second concerns the concept of vorticity and should be much more physical and placed in the introduction, if anywhere.

The book was fun to read only because of familiarity with the subject and the different approach revealed, but nothing in it requires urgent attention in the West, and for the novice it is not nearly as good as the World Meteorological Organization publications on the subject.

Some well-known pictures are reproduced ; for example Figure 30*a*, a superb photograph by Betsy Woodward, and she and the other photographers deserve acknowledgement just as much as the authors of the papers mentioned in the text.

R. S. SCORER

The atmosphere in action, by I. J. W. Pothecary. $8\frac{3}{4}$ in $\times$ 6 in, pp. 111, *illus.*, Macmillan and Co. Ltd., Little Essex Street, London WC2, 1965. Price : 15*s*.

The excellent daily weather maps on television, and the commentaries which accompany them, have given many people a considerable understanding and appreciation of the work of the Meteorological Office. However the majority remain ill informed concerning the practical difficulties of weather forecasting, and the vast amount of work and research that goes into it.

Mr. Pothecary, who is a Principal Scientific Officer in the Meteorological Office, supplies this information in a lucid and interesting manner. Beginning

with an account of the atmospheres of the planets, he then discusses in more detail the earth's atmosphere and general wind circulation. He proceeds to consider the influence of air masses on climate and weather throughout the world, with an important section on the westerly wind belt, which includes the British Isles. This leads on to the making of weather observations, a description of the instruments used, and the part played by artificial satellites, the latter being illustrated by excellent television pictures taken by TIROS III and IV. Finally we are told of the work of the meteorological services, with special emphasis on forecasting, and of the various investigations into weather problems at present being undertaken, including some up-to-date information on the use of computers, radar and satellites.

The book has an attractive format and is well illustrated with clearly drawn diagrams and photographs. It is written in terms which can be readily understood, and should help many people who have a little knowledge and wish to enlarge it but do not want to be confused by unnecessary scientific data. It will also prove useful as a supplementary book in the school or college library, providing valuable background knowledge for both the scientist and non-scientist.

F. R. DOBSON

The climate of London by T. J. Chandler. 10 in $\times$ 7½ in, pp. 292, *illus.*, Hutchinson and Co. Ltd., 178–202 Great Portland Street, London W1, 1965. Price : 70*s*.

This book describes the climate of London indicating how its various factors are modified by the urban area and topography, special reference being paid to differences between the built-up area, the suburbs and the rural surroundings.

Dr. Chandler has not only made very good use of existing climatological data (published and unpublished) for the London area, he has also contributed some valuable new material derived from special surveys which he has organized since 1958 and from motor-car traverses which he has made across the city.

The opening chapter describes the physical and cultural setting of the metropolis and is followed by nine chapters dealing with the following climatic elements ; pressure and weather types, wind, atmospheric pollution, radiation and sunshine, temperature, evaporation and humidity, visibility, cloud amount, and precipitation. The last two short chapters cover climatic regions of London and the consequences of an urban climate.

In order to set the broad climatic scene each of the chapters on climatic elements opens with a consideration of the data for Kew Observatory ; it then goes on to discuss the variations in and around London. Particular attention is paid to weather types and singularities, and the work of Brooks, Belasco and Lamb is extensively quoted in this connexion. Unpublished climatological summaries for Kew Observatory have been made good use of and by collecting together monthly tables published in *Observatories' Year Books* and *Monthly Weather Reports*, Dr Chandler has provided us with a number of new and useful summaries covering recent periods.

The chapter on temperature is the longest and perhaps the most interesting as it includes some of the author's original work on variations across the

city in various weather situations. The term 'heat-island' is extensively used but no definition of it could be found. However, the term 'cold-island', which is used much less often, is defined as a negative temperature anomaly. Deducing that a 'heat-island' is a positive temperature anomaly it is still puzzling to find references to 'London's heat island', as if it were a single ever-present entity, and the apparently tautological statement on page 180 'The influence of London's heat-island, more particularly on night-time temperatures, is very apparent'.

A fair number of misprints were noted and also a number of errors and obscurities. It is assumed on page 29 that the lag of a wet-bulb thermometer element will be a few seconds more than that of a similar dry-bulb element, whereas the reverse is true. On page 61, it is stated that *gusts* of 50 m.p.h. are equivalent to a strong gale. On page 239, discussing differences in the percentage changes in precipitation in successive decades for stations west of, within and east of London the author says, somewhat obscurely, 'If anything the balance was towards lower percentage increases within London than outside, but there was a large, overlapping diversity of increase in all three areas'.

When considering winds over London, Dr Chandler appears to the reviewer to overemphasize the effects of topography. For example, he explains differences in wind direction frequency between Kew and Kingsway as being due to topography, whereas they are probably almost entirely due to the different data periods used for the two stations (1948 and 1949, included in the Kingsway but not in the Kew period, both had unusually high frequencies of south-west and unusually low frequencies of north-east winds).

The chapter on visibility omits any reference to Brazell's paper on London fogs*. On page 236 there is a statement about the reporting of hail which is no longer true because the various forms of wintry precipitation have been separately reported since 1960.

In spite of these criticisms it is considered that Dr Chandler has produced a well-written, entertaining and thought-provoking account of London's urban climate and no student of the subject can afford to be without it. The volume is well produced and illustrated and includes a good list of references and a set of appendices giving daily mean and extreme values at Kew Observatory throughout the year. The index is restricted to place names only and an index of subjects covered would have been a useful addition.

H. C. SHELLARD

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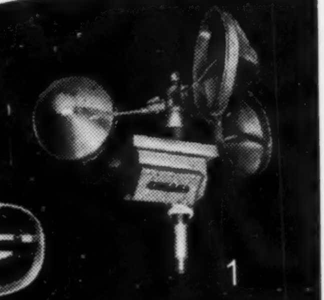

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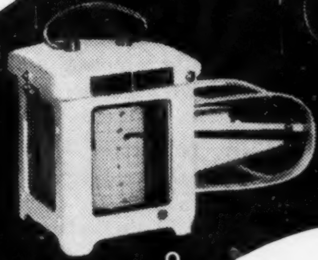

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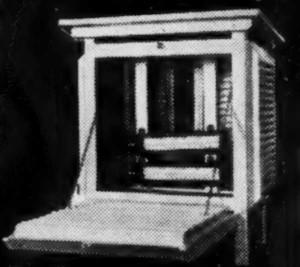

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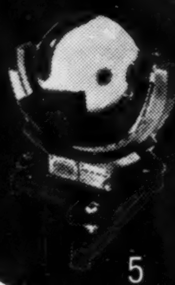

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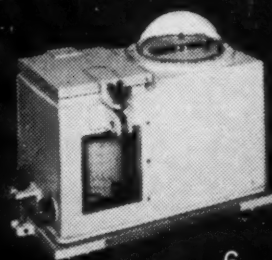

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THE METEOROLOGICAL MAGAZINE

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